Multi-Lepton Events at H1 and Search for Doubly-Charged Higgs Bosons

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Abstract.
Events with two or more leptons (electrons or muons) with high transverse momentum are measured in electron-proton collisions at HERA using the data sample collected in the period 1994-2005. Multi-lepton events at high transverse momenta are of special interest as these signature might reveal new physics beyond the Standard Model. An example is the single production of doubly-charged Higgs bosons $H^{\pm\pm}_{L,R}$, which couple to leptons of the i'th and j'th generation via Yukawa couplings $h^{L,R}_{ij}$. Results from a search for doubly-charged Higgs bosons in the decays into electrons, muons and taus are presented using data taken in the period 1994-2000. No evidence for doubly-charged Higgs production is found and we derive limits on the $h^{L,R}_{ee}$ and $h^{L,R}_{e\mu}$ Yukawa couplings as a function of the $H^{\pm\pm}_{L,R}$ mass.

Keywords: Higgs, Doubly-Charged Higgs, Leptons, H1, HERA
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INTRODUCTION

The H1 experiment has reported an excess of di-electron and tri-electron events with invariant masses above 100 GeV observed in ep collisions at HERA I in the period 1994-2000 [1]. In this talk results from a recent multi-lepton search at high transverse momentum are presented using the HERA I+II data samples collected in 1994-2005.

Multi-lepton events at high transverse momenta are of special interest as this signature might reveal new physics beyond the Standard Model. An example is the single production of doubly-charged Higgs bosons $H^{\pm\pm}_{L,R}$, which couples to leptons of the i'th and j'th generation via Yukawa couplings $h^{L,R}_{ij}$.

Doubly-charged Higgs bosons ($H^{\pm\pm}$) appear naturally in various extensions of the Standard Model (SM) in which the usual Higgs sector is extended by one or more triplet(s) [2, 3]. Examples are provided by some Left-Right Symmetric (LRS) models [4, 5] with a spontaneously broken $SU(2)_L \times SU(2)_R \times U(1)_{B-L}$ symmetry. These models are of particular interest as Higgs triplets can give Majorana masses to neutrinos, which are known to be massive from recent experimental data. Results from a search for doubly-charged Higgs bosons in the decays into electrons, muons and taus are presented using data taken in the period 1994-2000.

TABLE 1. H1 preliminary event yields for 1994-2004 $e^{\pm}p$ data (L=163 pb^{-1}) of the different multi-lepton channels for $M_{ll'} > 100$ *GeV*. The numbers are compared with the expectations from the Standard Model and from pair production only.

channel	data events	Standard Model	Pair Production
ee	3	0.4 ± 0.1	0.32
$\mu\mu$	0	0.04 ± 0.02	0.04
$e\mu$	0	0.31 ± 0.03	0.31
eee	3	0.31 ± 0.08	0.31
$e\mu\mu$ $(M_{e\mu})$	1	0.04 ± 0.01	0.04
$e\mu\mu$ $(M_{\mu\mu})$	1	0.02 ± 0.01	0.02

EVENTS WITH MULTI-LEPTONS

Events with clearly identified isolated electrons and muons at high transverse momentum (p_T) are selected and classified into the following final state topologies: *ee*, *eee*, $e\mu$, $\mu\mu$, $e\mu\mu$, etc.). Within the Standard Model such events are mainly produced via photon-photon collisions. The invariant mass distribution of the two highest p_T electrons are shown for the *ee* and *eee* classes in Fig. 1 using 163 pb^{-1} of HERA I+II data. The event yields for all classes after the cut $M_{\ell\ell'} > 100$ GeV are shown in Tab. 1. An excess of data events over the SM expectation is seen in the *ee* and *eee* classes.

For some event classes the same analysis was repeated using the most recent $e^{-}p$ dataset from 2004/05 (21 pb^{-1}), see Fig. 1. No new event was found for $M_{\ell\ell'} > 100$ GeV in the analysed $ee, e\mu, eee, e\mu\mu$ event classes in agreement with the SM expectation.

DOUBLY-CHARGED HIGGS PRODUCTION

The search for single doubly-charged Higgs production is based on studies of dilepton production *ee*, $\mu\mu$ [1, 6], and new multi-lepton searches for the $e\mu$ and $\tau\tau$ final states at high p_T. The analyses use data collected at HERA I from 1994-2000 (*ee*, $\mu\mu$ and $e\mu$) and 1999/2000 ($\tau\tau$). The selections involving electrons and muons are identical to those described in the previous section. Tau pairs are searched for taking into account leptonic and hadronic τ-decays in the event classes $\tau\tau \to e\mu, ej, \mu j, jj$ plus missing energy from the unobserved tau neutrinos. The invariant mass of the $H^{\pm\pm}$ is fitted by exploiting energy and momentum conservation resulting in a resolution of $2.5 - 4.0$ GeV.

Further $H^{\pm\pm}$ selection criteria are applied to all multi-lepton final states. Events where the charges of the highest p_T leptons are measured to be inconsistent with the $H^{\pm\pm}$ hypothesis are rejected. For the $H^{\pm\pm} \to e^{\pm}e^{\pm}$ decay both electrons are required to have large transverse energies in the calorimeter. After the final selections only one candidate event ($H^{\pm\pm} \to e^{\pm}e^{\pm}$) is found for $M_H > 100$ GeV. Various limits are derived as function of M_H at 95% CL on the product $\sigma \times$ BR for each decay topology, see Fig 2 left, and on the coupling $h_{ee}^{L,R}$ assuming a model with democratic couplings BR$(H^{\pm\pm} \to l^{\pm}l^{\pm}) = 1/3$ (right). In Fig. 3 exclusion limits on $h_{ee}^{L,R}$ (left) and $h_{ee}^{L,R}$ (right) are shown as function of M_H assuming a decay branching ratio of 100% for each case. For comparison direct and indirect limits from other experiments are shown [7, 8, 9].

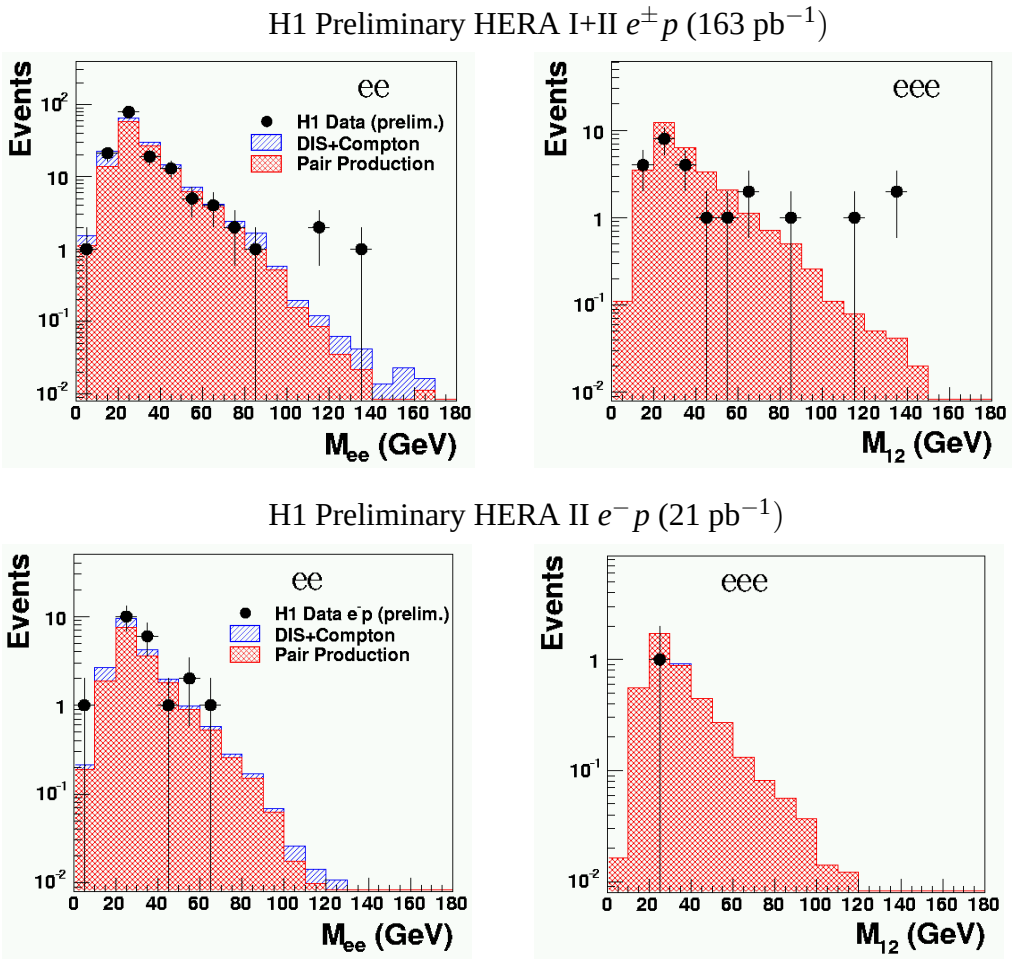

FIGURE 1. Invariant masses M of the two highest p_T leptons compared to expectations for *ee* and *eee* classified event. The data samples correspond to an integrated luminosity of 163 pb^{-1} (1994+2004, top figures) and to 21 pb^{-1} of the recent e^-p data taken in 2004/05 (bottom).

CONCLUSION

Multi-lepton events with electrons and muons are studied using HERA I+II data. No new di-electron and tri-electron events are observed with invariant masses above 100 GeV in the most recent e^-p dataset. More integrated luminosity is required to enhance the sensitivity at high masses. No evidence for doubly-charged Higgs production is found and various limits on $H^{\pm\pm}_{L,R}$ Yukawa couplings $h^{L,R}_{\ell\ell'}$ were derived.

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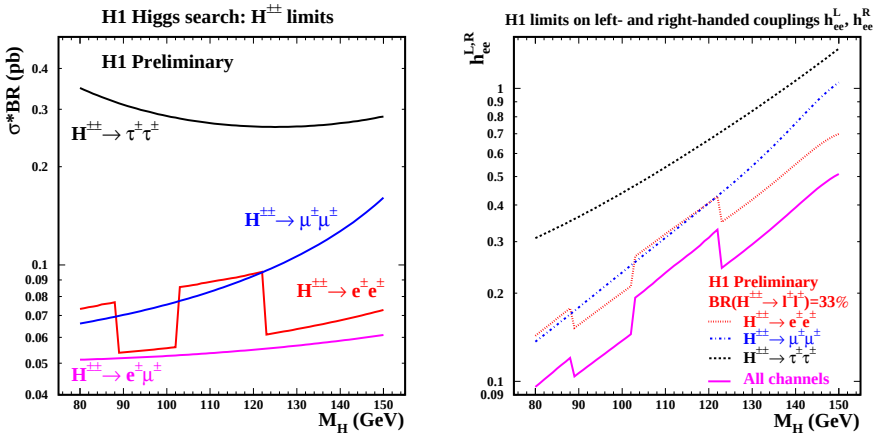

FIGURE 2. Left: upper limits at 95% CL on $\sigma(e^{\pm}p \to e^{\mp}H^{\pm\pm}X) \times \mathrm{BR}(H^{\pm\pm} \to \ell^{\pm}\ell'^{\pm})$ as a function of the doubly-charged Higgs mass. Right: exclusion limits on the coupling $h_{ee}^{L,R}$ at 95% CL as function of M_H for the decay channels $H^{\pm\pm} \to e^{\pm}e^{\pm}, \mu^{\pm}\mu^{\pm}, \tau^{\pm}\tau^{\pm}$ and their combination (full curve) assuming democratic couplings, ie. $\mathrm{BR}(H^{\pm\pm} \to \ell^{\pm}\ell^{\pm}) = 1/3$.

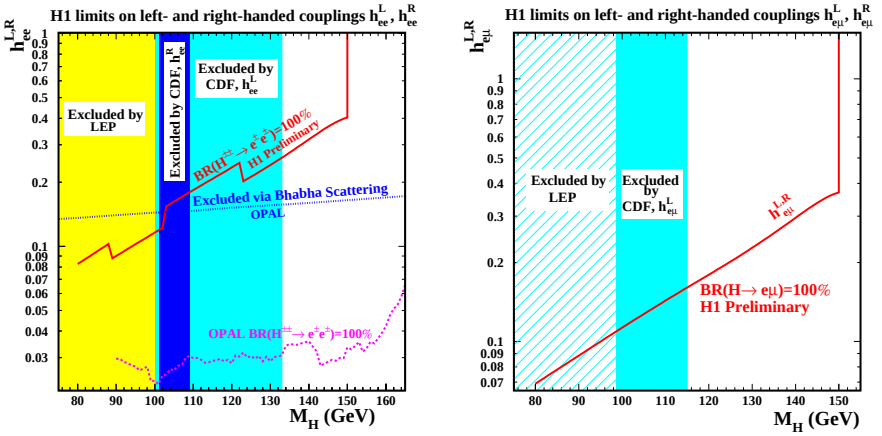

FIGURE 3. Left: exclusion limits on the coupling $h_{ee}^{L,R}$ at 95% CL as a function of the doubly-charged Higgs mass for the decay $H^{\pm\pm} \to e^{\pm}e^{\pm}$ assuming $\mathrm{BR}(H^{\pm\pm} \to e^{\pm}e^{\pm}) = 1$. Right: exclusion limits on the coupling $h_{e\mu}^{L,R}$ at 95% CL as a function of M_H for the decay $H^{\pm\pm} \to e^{\pm}\mu^{\pm}$ assuming $\mathrm{BR}(H^{\pm\pm} \to e^{\pm}\mu^{\pm}) = 1$. The results are compared to direct and indirect limits (Bhabba scattering) obtained by OPAL (single production), and LEP and CDF (pair production).

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